U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, Secretary
WEATHER BUREAU
F. W. Reichelderfer, Chief

NATIONAL SEVERE STORMS PROJECT

REPORT No. 7

The Vertical Structure of Three Dry Lines as Revealed by Aircraft Traverses

by
E. L. McGuire
National Severe Storms Project, Kansas City, Mo.

Washington, D. C.
April 1962

CONTENTS

THE VERTICAL STRUCTURE OF THREE DRY LINES AS REVEALED BY AIRCRAFT TRAVERSES[1]

E. L. McGuire
National Severe Storms Project
Kansas City, Missouri

ABSTRACT

Aircraft data, in conjunction with synoptic data, are analyzed for three cases of sharp moisture discontinuity near the ground. Aircraft traverses of the "dry line" yielded horizontal gradients of mixing ratio, of the order of several grams per kilogram per kilometer, through the discontinuity surface. The discontinuity surface was found to be nearly vertical through the lower 3000 to 4000 feet. No density contrast across the dry line was apparent.

I. INTRODUCTION

The terms "dry line" and "dew point front" have been used to describe a line, other than a warm or cold front, across which a sharp moisture discontinuity exists at the earth's surface. Discontinuity lines of this type are found most often in western Texas, where they form a boundary between the continental tropical air mass of the southwestern United States and the maritime tropical air flowing northward from the Gulf of Mexico. They are also sometimes observed farther north through western Oklahoma, Kansas, and Nebraska. These lines are sometimes drawn eastward by migratory depressions and are often observed in proximity to outbreaks of severe convective weather.

Fawbush, Miller, and Starrett, [2], in their pioneer work on the forecasting of tornadoes, considered the 55° F. surface dew point isotherm as a western boundary for tornado development. They considered the transition zone between moist and dry air as a zone of potential instability.

It is not well understood just what role the dry line plays in the genesis of severe weather. One hypothesis has been that the very dry air on the west side of the line is more dense than the moist air to the east and that there is a mechanical lifting of the moist air, as along a cold front. Other forecasters believe that the effect is more thermodynamic in nature. Sanders [5] found a preferred region for the initiation of precipitation along the zone of strong gradients of potential wet-bulb temperature on the western side of moisture injections into the central United States.

[1] Presented at the Conference on Severe Storms, American Meteorological Society, St. Louis, Mo., May 10, 1960.

It is known that a strong dry line may remain quasi-stationary for several days without becoming active, but under certain conditions it appears to act as a generation line for active squall lines. Because of this apparent association, one of the aims of the Tornado Research Airplane Project[2] has been to investigate the nature and structure of the dry line. One flight during which a dry line was traversed several times had been described by Beebe [1] and by Fujita [3].

2. INSTRUMENTATION OF AIRCRAFT

A description of the sensing and recording equipment used on the P-38 research airplane has been given by Lee and David [4]. The lag in the beginning of response to sharp changes for both the aspirating thermometer and the infrared hygrometer was found to be less than two seconds. Comparison flights in which the airplane circled the radiosonde balloon during ascent were made in 1958 and 1959. These showed good agreement in temperature and humidity measurement. They indicated that the infrared hygrometer used on the airplane is much more sensitive than the radiosonde hygrometer for mixing ratio values of less than 12 gm./kg.

A part of the data from the sensing instruments was recorded by photographing a modified instrument panel (photo panel). Temperature, pressure, and humidity were recorded in analog form on Brown Recorders. A Veeder-Root counter was used for time synchronization. The counter number changed each 15 seconds, triggering the photo-panel camera and marking the recorder roll. A tape recorder was used to record remarks by the pilot, which were prefaced by the current Veeder-Root number. Information on the tape recorder was synchronized with the Brown recorder through an electrical contact manually actuated by the pilot.

3. METHOD OF INVESTIGATION

Two flights during the 1959 season, and one during the 1960 season, were dispatched with the primary objective of dimensioning the dry line. Flights were conducted in a vertical step pattern, with individual legs at constant pressure altitude and in a path as nearly normal to the dry line as could be determined. When the sharp humidity change was noted, a point on the ground such as a road, bridge, or stream was chosen as a reference. On each succeeding traverse, the pilot read the Veeder-Root counter number into the voice recorder and also marked the recorder chart when directly over the reference point. Thus a vertical line was established. In the following diagrams this is labeled the "marker line". The pilot also recorded frequent fixes on either side of the marker line which aided in careful post-navigation of the flights. The accuracy of the post-navigation is limited by the ability of the pilot to determine when he was directly over a ground point and also by the necessity of using a mean ground speed to locate some points. It is believed, however, that the error in lateral location of points is generally less than one-half mile close in to the marker line.

[2]Now expanded and renamed National Severe Storms Project.

4. DESCRIPTION OF DATA

Flight 37, conducted between 1503 and 1555 CST on May 26, 1959, yielded the strongest moisture gradients of the three cases and will be described in detail. The sea-level chart based on 1400 CST observations (fig. 1), shows a weak wave cyclone over the Texas Panhandle with a line of sharp moisture discontinuity extending through this center and southward. Note the marked drop in dew point from east to west across this line and the wind shift from southerly to westerly. The point where the traverses were made is shown just NW of Mineral Wells, Tex. Only scattered cumulus and altocumulus clouds were present in the area of investigation.

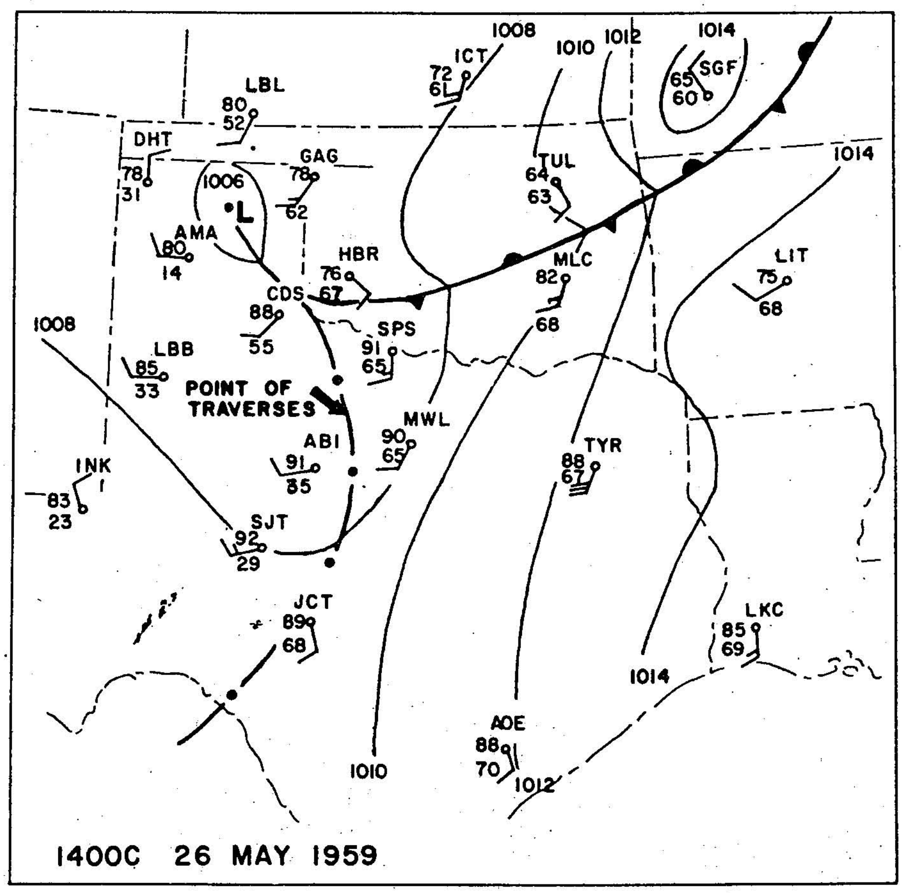

Figure 1.- Sea-level chart for 1400 CST, May 26, 1959 showing location of dry line (dash-dotted line) at time Flight 37 was dispatched.

Figure 2 shows graphs of pressure and mixing ratio against flight time for eleven traverses at nearly constant pressure altitude past the reference point. Notice that sharp discontinuities in moisture were observed below about 750 mb., while above that level the fluctuations were unsystematic. After the last traverse at 650 mb., a sounding descent was begun approximately over the reference point. Following this descent, three traverses were made at about 940 mb. All of these showed very large moisture gradients, the strongest rate of change being 6 g./kg. in 33 seconds of flight time (about 1 ½ mi.).

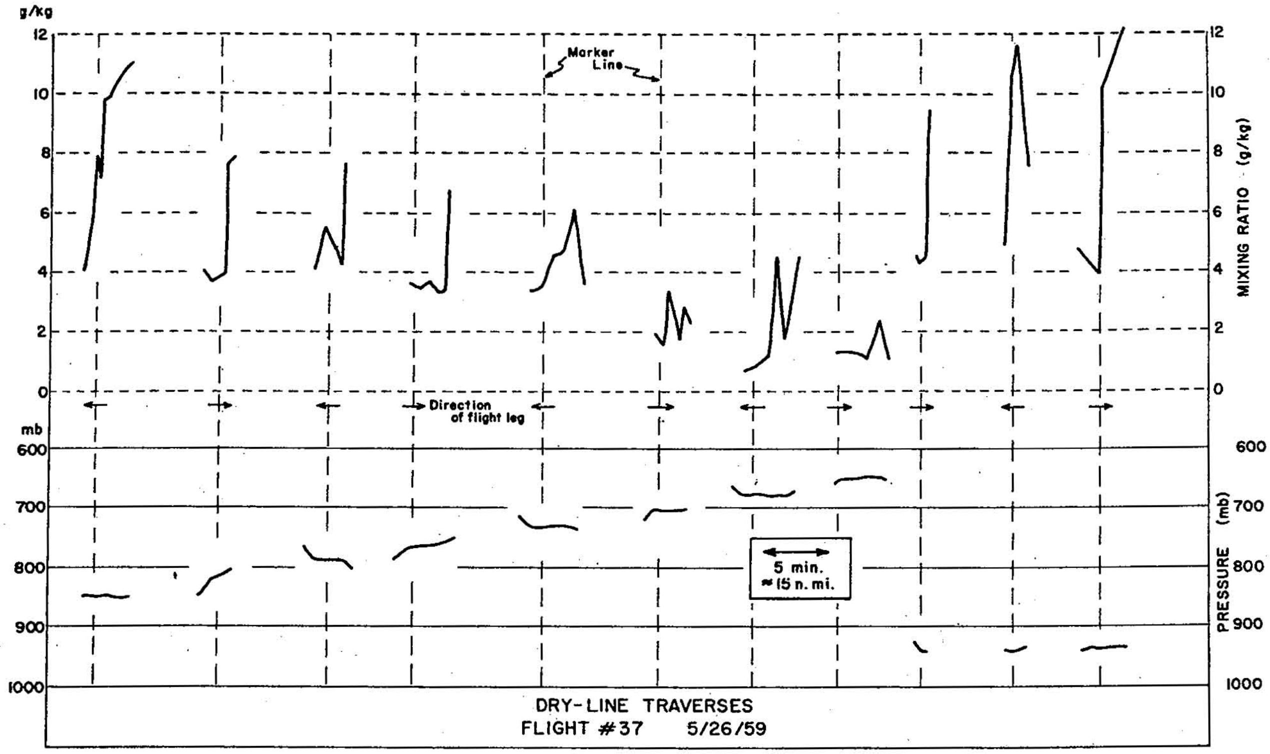

Figure 2.- Graphs of mixing ratio against flight time for eleven traverses through dry line. Flight 37, May 26, 1959. Time and space scale indicated in inset.

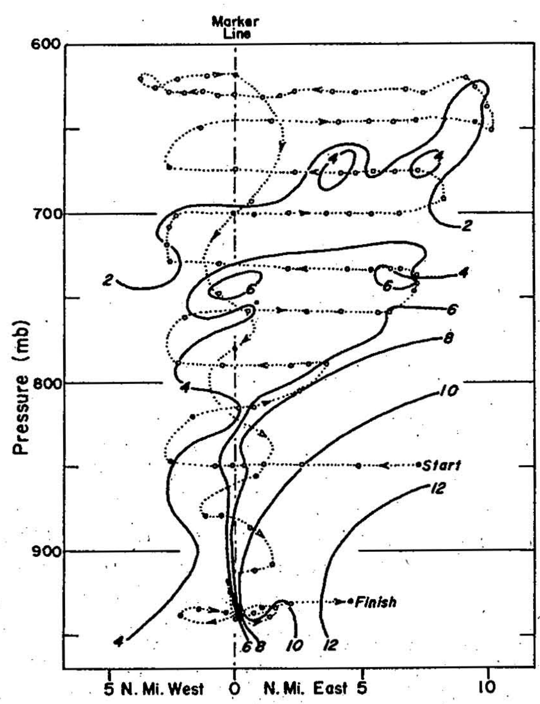

Figure 3.- Cross-section analysis of moisture distribution, Flight 37. Dots and short arrows represent path of airplane and small circles locate points where data were read. Isopleths represent mixing ratio in g./kg.

In figure 3, a cross-section analysis of the moisture pattern is given. The path of the aircraft is indicated by the short arrows, and the dots locate points where data were read. The interval between 6 and 8 g./kg. seems to be the interval of most rapid change and was chosen as representing the dry-line boundary zone. This boundary can be recognized up to near 750 mb. and is sharpest below 850 mb. We observe a nearly vertical boundary for the lower 100 mb. and a slope to the east at higher pressure altitude. Notice that near the ground the boundary appears to be displaced somewhat to the east and is more diffuse.

5. THERMAL AND DENSITY CONSIDERATIONS

The Fort Worth and Midland adiabatic diagrams for 1800 CST (fig. 4) illustrate the thermal and moisture characteristics of the air masses well east and west of the dry line near the time of Flight 37. The Fort Worth sounding is typical for northward-moving maritime tropical air in spring and summer. Note the very high moisture content at lower levels, capped by a temperature inversion near 800 mb. The Midland sounding shows a nearly dry-adiabatic lapse rate to 700 mb. with potential temperature of 310° K. It is seen that below 800 mb., the air was dry and warm to the west and moist and cooler to the east, while little difference was observed at lower pressures.

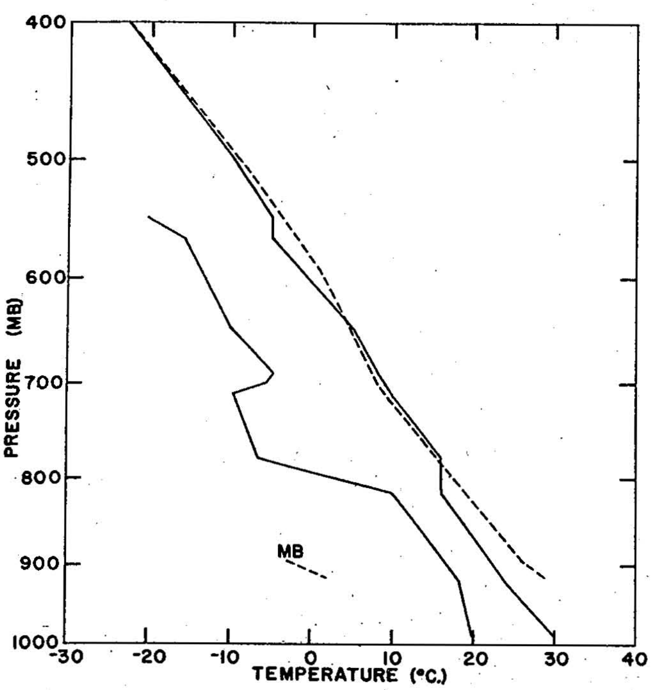

Figure 4.–Rawinsonde ascents at Fort Worth (solid lines) and Midland (dashed lines) for 1800 CST, May 26, 1959. Right hand curve in each case is temperature and left hand curve is dew point.

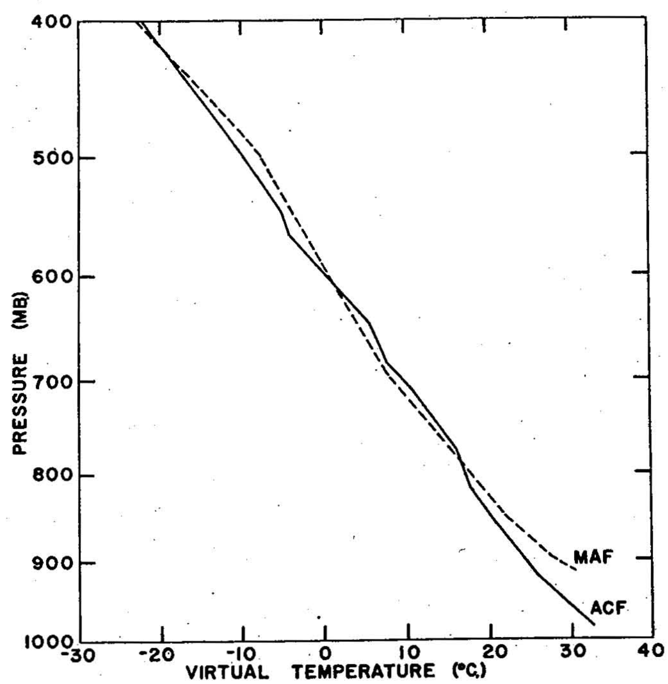

Figure 5.– Virtual temperature versus pressure for Fort Worth (ACF) and Midland (MAF) for 1800 CST, May 26, 1959.

In figure 5, Virtual temperature is plotted against pressure for Fort Worth and Midland. This shows that even with moisture considered, the air at Fort Worth below 800 mb. has lower virtual temperature and hence greater density than the air over Midland. To examine the density variations in the immediate vicinity of the dry line, data were selected from traverses on either side of the sharpest moisture gradient in figure 3, the points involved being

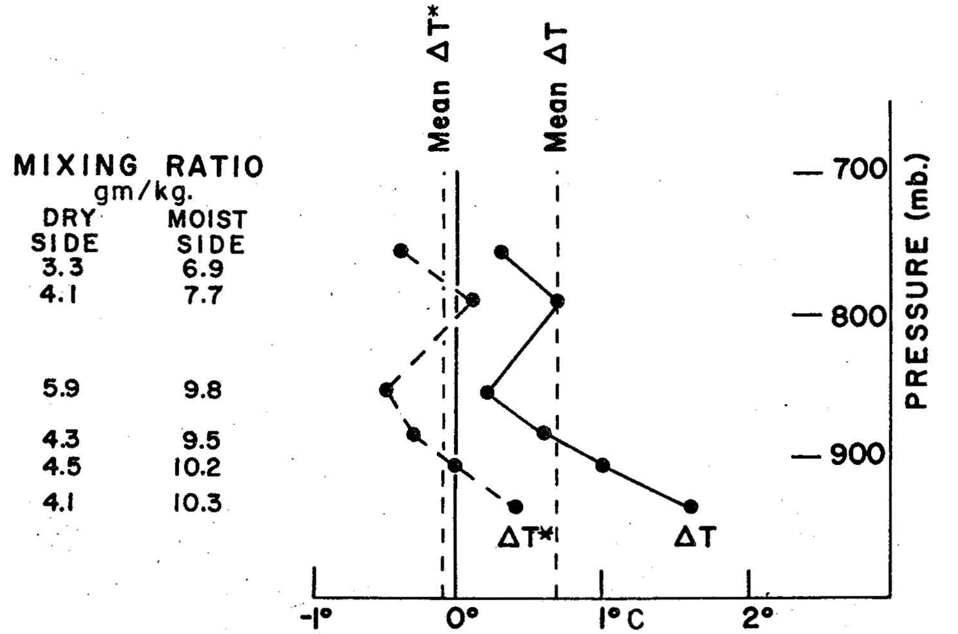

Figure 6.- Temperature change (ΔT) and virtual temperature change (ΔT*) observed on six traverses through dry line (Flight 37). The mean temperature variation (moist to dry side) was $+0.7^{\circ}$C. while the mean variation of virtual temperature was only -0.1°C.

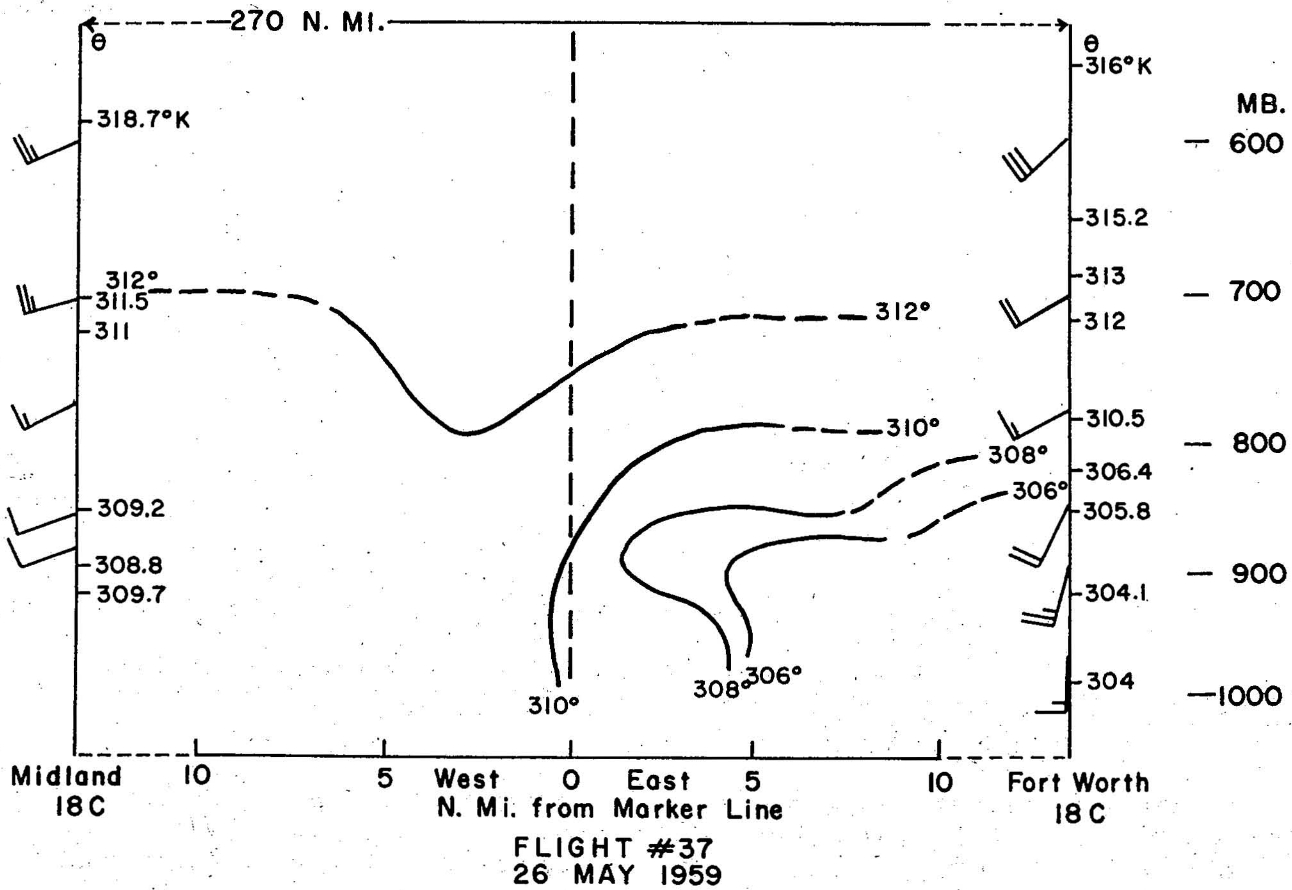

Figure 7.- Cross-section showing distribution of potential temperature across dry line (Flight 37). Solid portions of isentropes were analyzed from aircraft data and dashed extensions were derived from Fort Worth and Midland soundings (shown on either side of cross section for comparison).

1/2 to 2 mi. apart. Figure 6 shows that despite the appreciable temperature difference in this small distance, there was a much smaller difference in virtual temperature across the sharpest portion of the dry line.

Figure 7 shows the potential isentropes analyzed from aircraft data, which may be compared with the potential temperatures tabulated in the figure for Fort Worth and Midland (2 - 3 hr. after flight time). It is seen that virtually all the lower-level temperature contrast between these stations, 270 mi. apart, was concentrated in a region about 5 mi. across. Comparison of figures 3 and 7 reveals a close resemblance between the patterns of potential temperature and mixing ratio.

6. OTHER EXAMPLES

In two other cases, "stair-step" traverses of dry lines were carried out. Analyses of the mixing-ratio patterns are shown in figures 9 and 11. The corresponding surface charts (figs. 8 and 10) show that there were large overall moisture contrasts between the two air masses involved. Again (figs. 9 and 11) the horizontal gradients of moisture were very large, when considered in comparison with the synoptic scale, although they were very much weaker than in the example discussed above.

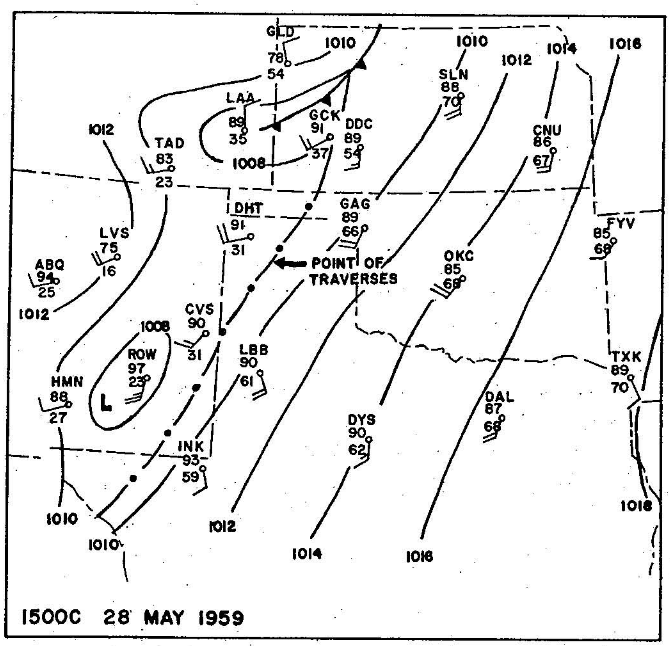

Figure 8.- Sea-level chart for 1500 CST, May 28,1959 near time of Flight 39, showing location of dry line (dash-dotted line) and place where traverses were made.

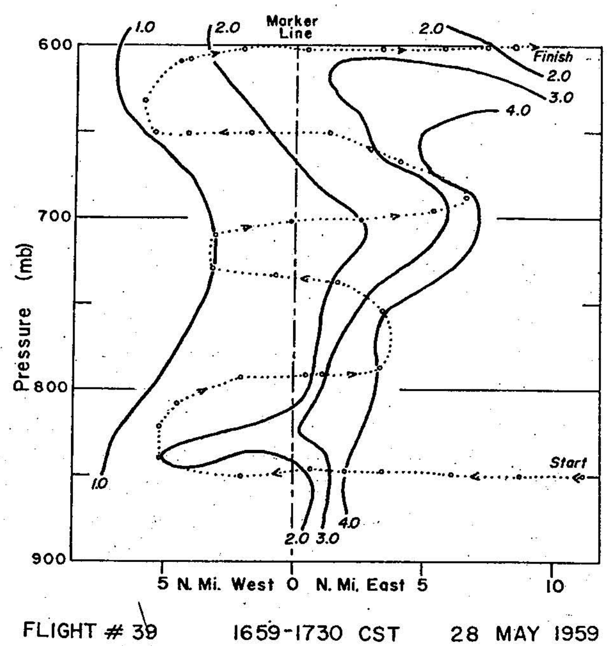

Figure 9.- Cross section showing path of plane and observed moisture distribution (mixing ratio) for Flight 39.

In these cases, as in the other case, there was evidently little density contrast across the dry line (over the distance covered by the aircraft traverses). Particularly in Flight 39 (fig. 9), the zone of sharp moisture gradient again had a very steep slope.

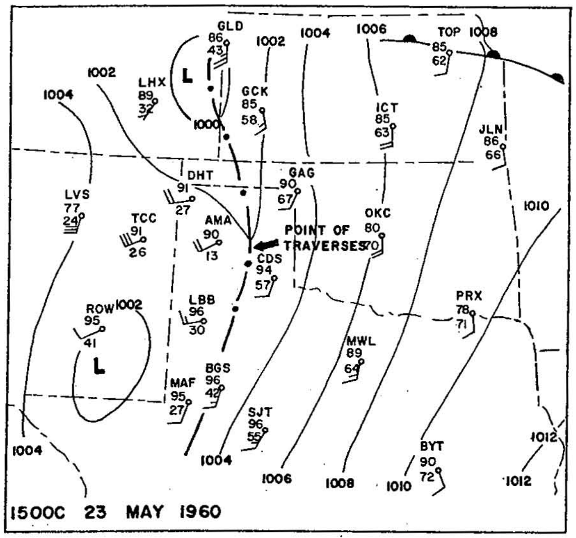

Figure 10.- Sea-level chart for 1500 CST, May 23, 1960, near time of Flight 56, showing location of dry line, and place where traverses were made.

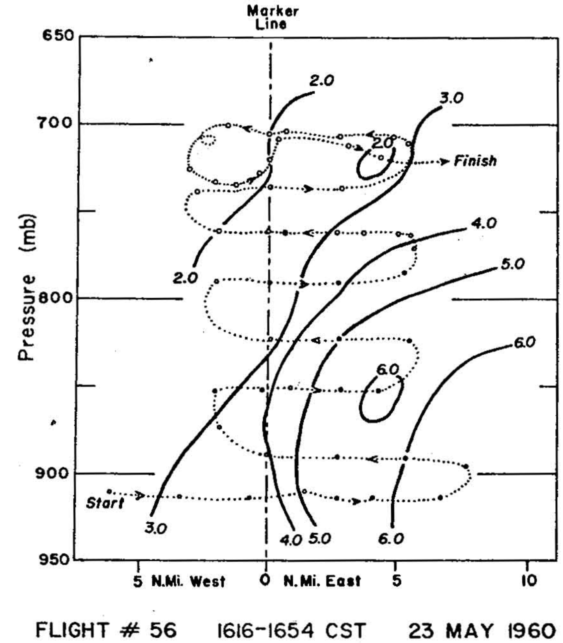

Figure 11.- Cross section showing path of plane and observed moisture distribution (mixing ratio) for Flight 56.

7. CONCLUSIONS

The limited number of cases for which detailed flight data are available allows only quite tentative conclusions; however, some bases for hypothesizing seem to have been established. The pattern which emerges is that of a sharp boundary between the northward-streaming Gulf air and the warm, dry air of semidesert origin. The close juxtaposition of these contrasting air masses is apparently maintained kinematically (note that the low-level wind field is frontogenetic). The sharpness of the dry-line zone indicates that this frontogenesis is sufficient to offset the effects of lateral mixing. Since the general configuration seems to involve rather delicately balanced static and kinematic factors, this configuration may undergo considerable fluctuations, especially of a diurnal nature. The near absence of any slope in the dry-line surface in figure 3 is compatible with the apparent lack of any density difference, but this is not necessarily representative of all times of the day.

It is interesting to consider, for instance, the effect of nocturnal radiation along a line separating very dry from very moist air. We can visualize comparatively large nocturnal cooling west of the dry line, due to the absence of a re-radiating moisture blanket aloft. This would result directly in a tendency to decrease the temperature contrast across the dry line.

In addition, the cold air would tend to drain eastward, undercutting the moist air and perhaps leading to some diffusivity of the contrasting dry and moist air during early morning hours. Increased strength of surface winds due to daytime heating would presumably contribute to kinematic frontogenesis by afternoon. Although detailed observations are not available, synoptic analyses suggest that the dry line is more intense in the afternoon than in early morning.

The effects of diurnal variations, particularly in the vertical flux of momentum, offer an area of interest for further investigation. Study of such variations is likely to be important in determining the role of the dry line in generating convective activity, since diurnal variations of convergence and of frontal slope, in addition to variations in air-mass structure, are factors in the formation of convection.

Since squall lines frequently appear to form at or near dry lines, additional investigations will be carried out as a primary objective of NSSP. These will in future involve wind measurements as well as measurement of the other meteorological quantities, so that a study of kinematic properties can be made.

REFERENCES

1. Beebe, R. G., "An Instability Line Development as Observed by the Tornado Research Airplane," *Journal of Meteorology*, vol. 15, No. 3, June 1958, pp. 278-282.

2. Fawbush, E. J., R. C. Miller, and L. G. Starrett, "An Empirical Method of Forecasting Tornado Development," *Bulletin of the American Meteorological Society*, vol. 32, No. 1, Jan. 1951, pp. 1-9.

3. Fujita, T., "Structure and Movement of a Dry Front," *Bulletin of the American Meteorological Society*, vol. 39, No. 11, Nov. 1958, pp. 574-582.

4. Lee, J. T., and C. L. David, "The Tornado Research Airplane, 1958-1959," *Bulletin of the American Meteorological Society*, vol. 42, No. 4, Apr. 1961, pp. 231-238.

5. Sanders, R. A., "An Approach to Quantitative Precipitation in the Central United States Basin by Use of the Theta Prime Chart," Unpublished Manuscript, U. S. Weather Bureau, Kansas City, Mo., 1957.

USCOMM-WB-DC